5.7.2 Damage Due to Hydrogen Embrittlement.

Hydrogen embrittlement (hydrogen induced crack formation) can become noticeable in several different ways:

- **Decrease in ductility** and **strength**, especially under **slow tensile strain** and **stress concentrations**.

- Accelerated **crack growth rates** in engine parts with cracks. This leads to brittle fractures which can occur even under very low external loads, depending on the amount of hydrogen. These fractures can occur several minutes after hydrogen absorption, or spontaneously after years of operation. Typical damages in aircraft engines are:

- Cracks and fractures in **cadmium-coated**, hardened/heat-treated steel parts such as thread inserts or disk springs (Ill. 5.7.2-1).

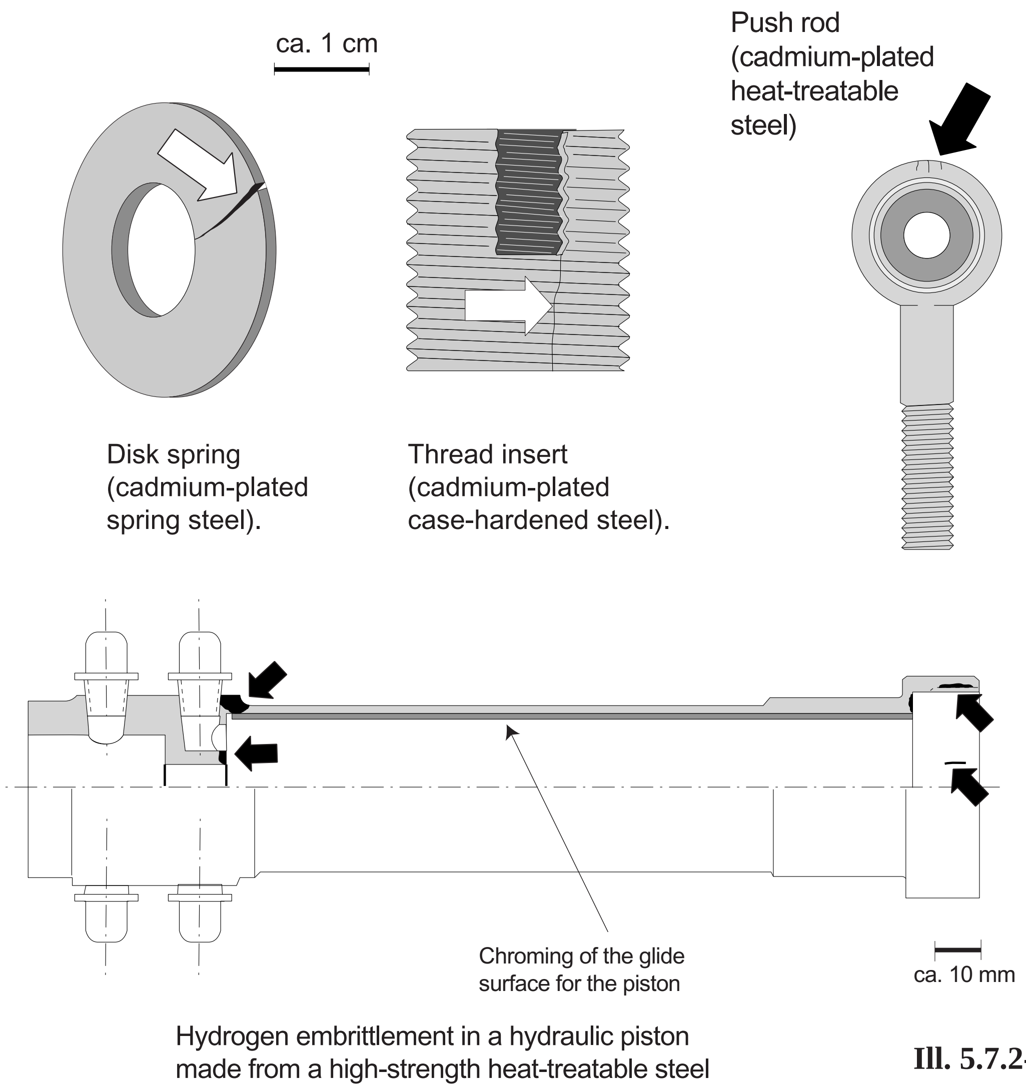
- Brittle fractures in cast parts made from **high-strength steels** (maraging steels, precipitation-hardened steels) in unfavorable material states (Ill. 5.7.2-1)

- Probable crack initiation inside **titanium forging blanks** around pores that were not forged out. This crack development has been confirmed both immediately after forging (when heat-treatment occurred the following day), and on finished heat-treated parts under operating loads.

- Inner crack formation in **case-hardened gears** (Ill. 5.7.2-2) due to hydrogen absorption during **carbonizing** in a gaseous atmosphere (**case hardening**)..

- Crack initiation in the **welding seam area** of low-alloy steels after water was absorbed during welding (Ill. 5.7.2-3).

Crack growth due to the influence of hydrogen. The stronger the material, the more sensitive it is.

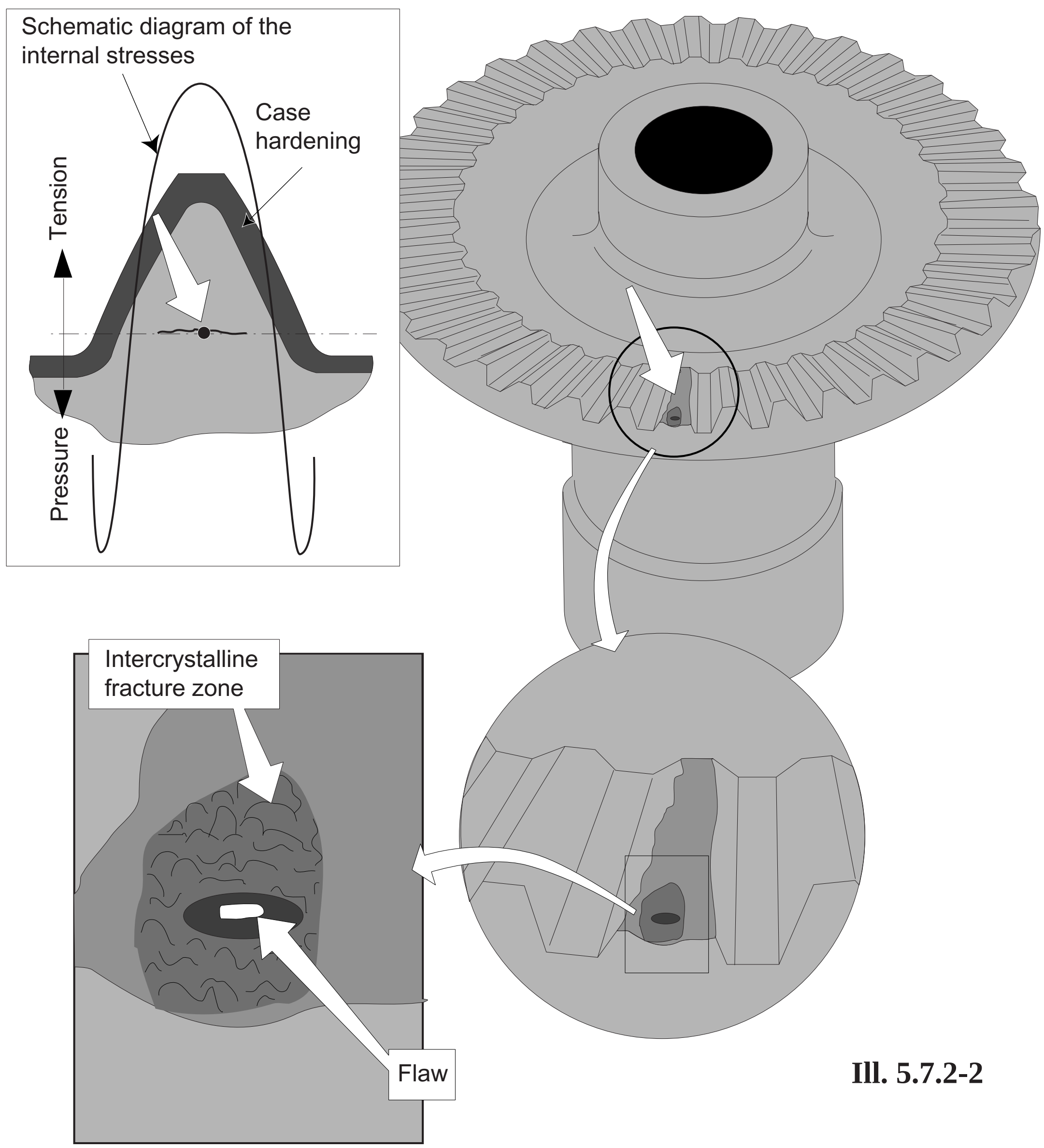


Ill. 5.7.2-1

Ill. 5.7.2-1: *Typical parts in which hydrogen embrittlement damage is frequently reported are hardened or high-tempered parts made from low- and high-alloy steels with* ***galvanic coatings****, especially* ***cadmium coatings*** *(Lit 5.7-15). The supply of atomic hydrogen seems to be especially intense during this process. Typical parts include disk springs, thread inserts, spring washers, plain washers, and threaded rods (top diagrams).*

The lower diagram shows a hydraulic piston from a thrust jet adjuster made from a high-strength heat-treated steel. After a restorative ***chrome-plating*** *procedure, certain areas (arrows) that were not chrome-plated developed cracks with typical characteristics of hydrogen embrittlement (Ill. 5.7.1-2).*

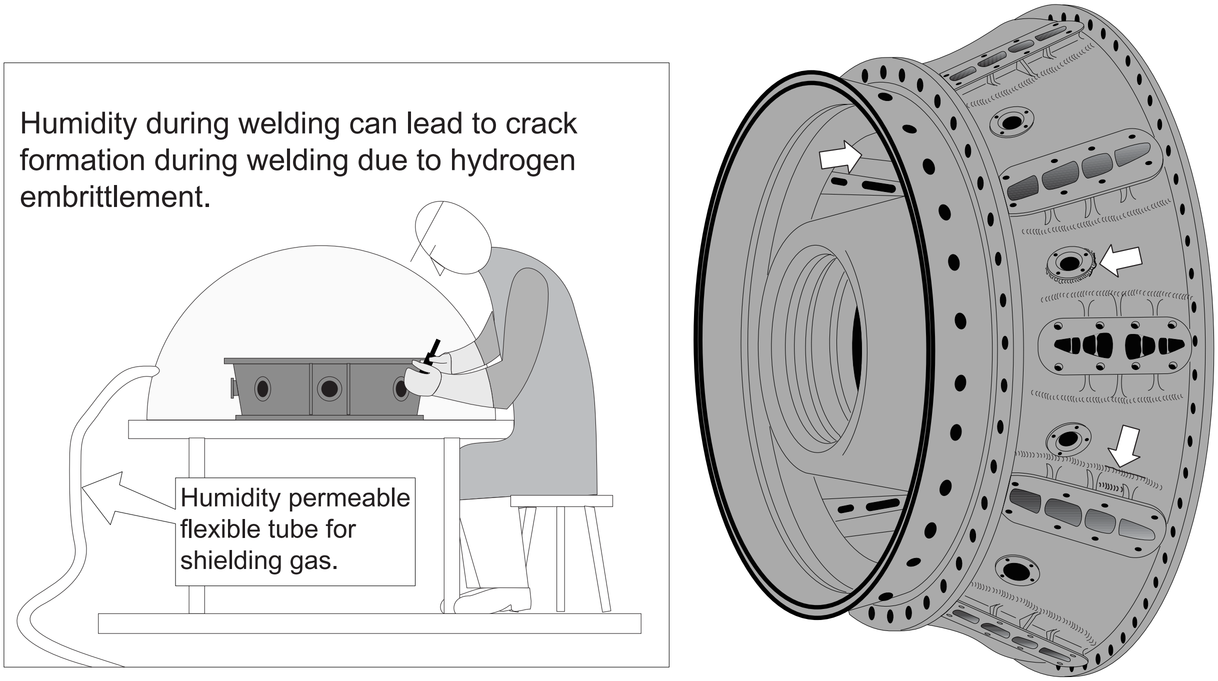
Tooth failure due to hydrogen embrittlement that was related to case hardening.



Ill. 5.7.2-2

Ill5.7.2-2*: Teeth fractures on* ***case-hardened gears*** *due to inner crack development following hydrogen embrittlement. The gears evidently absorb hydrogen during case-hardening (see page 5.7-8). The damage then seems to occur as follows (Lit. 5.7-11): the high internal stresses in the case-hardened layer at the tooth surface induce high tension residual stresses in the tooth core (top left diagram). The smaller and more filigreed the tooth, the greater the danger that a circular* ***hydrogen embrittlement crack*** *will develop at internal notches* ***within several hours****. An intercrystalline hydrogen-induced brittle fracture then originates in this crack, and can later lead to a* ***dynamic fatigue fracture*** *under the operating loads, destroying the gearing.*

Hydrogen induced crack formation in welds of compressor aud turbine casings made from low alloy steels.



Ill. 5.7.2-3

*Comparable hydrogen embrittlement cracks now are also found in teeth of large **gears from wind power plants**. Even failures during operation may have occurred.*

***Ill. 5.7.2-3:** Older engine types often have **compressor housings**/casings that are **welded constructions** made from low-alloy heat-treated steels. Similar housings are found in modern engines near the outlet of the low-pressure turbine. The complex shape of these housings causes them to develop high tension residual stresses that are induced by welding during new part manufacture or repair procedures. If **moisture** (e.g. in the shielding gas or as condensation water) is present during the welding process (see Ill.5.7.1-3 and volume 4 Ill. 12.2.1.3.1-18), then hydrogen from the moisture can be absorbed by the melt (Lit 5.7-12). This can lead to delayed crack initiation in the weld seam area during storage, manufacturing processes, or operation (arrows show typical crack-prone part zones). For this reason, if this type of crack is suspected, SEM inspections of the fracture surface should be conducted first of all, in order to confirm **characteristic signs of hydrogen embrittlement** (see Ill. 5.7.1-2).*

5.7.3 Measures Against Damage Due to Hydrogen Embrittlement:

There are a number of preventive and corrective measures available to prevent damage due to hydrogen embrittlement:

- **Avoiding hydrogen sources:**

Use of suitable baths (etching baths, cleaning baths, galvanic baths); e.g. “stable“ Cd baths or Zn baths (Lit. 5.7-12). Testing the baths for any changes (e.g. contaminants, composition) that could cause hydrogen embrittlement. This could be done, for example, by determining the hydrogen content in part-relevant samples or experimentally through suitable toughness tests (Ill.5.7.1-6).

Preventing hydrogen absorption in metal melts during welding and casting by ensuring a dry environment: Drying the welding electrodes (especially with covered electrodes), using dry linings that come into contact with the melt.

Use of dry **shielding gas**. Avoiding use of **water permeable gas feed hoses**. Certain synthetic hoses have been proven to be unsuitable because diffusion of moisture from thw outer air.

Drying or sufficiently heating (e.g. above 100 °C) the parts to be welded immediately before welding in order remove any possible condensation water from the surface.

- **Strain hardening the surfaces before coating** (shot peening, rolling).

- **Optimized coating buildup**, e.g. through preparatory sulfimate nickel-plating followed by application of the actual functional coating.

- **Avoiding coatings** with application processes that have a risk of water absorption (e.g. avoiding Cd coatings)**.**

- Special care **when coating high-strength materials**, especially steels.

- If possible, **no maximization of the hardness/strength potential**, e.g. sufficiently high tempering temperatures with heat-treated steels (Ill. 5.7.1-5).

- **Estimation of the embrittlement danger** through testing suitable representative samples (e.g. notch impact sample tests or slow tensile tests, Ill. 5.7.1-6).

● **Degasifying ("disembrittling"):** Heating the material to about 200-250°C over several hours (one hour to several hours; Ill. 5.7.1-7) **immediately after it is charged with hydrogen** (Ill. 5.7.1-1, Lit. 5.7-10). If, during or after the hydrogen absorption phase, largely sealing **"barrier coatings"** have been separated, then degasification through effusion of the material (escape through the surface) will at least be somewhat impeded.

The degasification effect can then only be expected to **balance the hydrogen concentration** in the volume of the part.